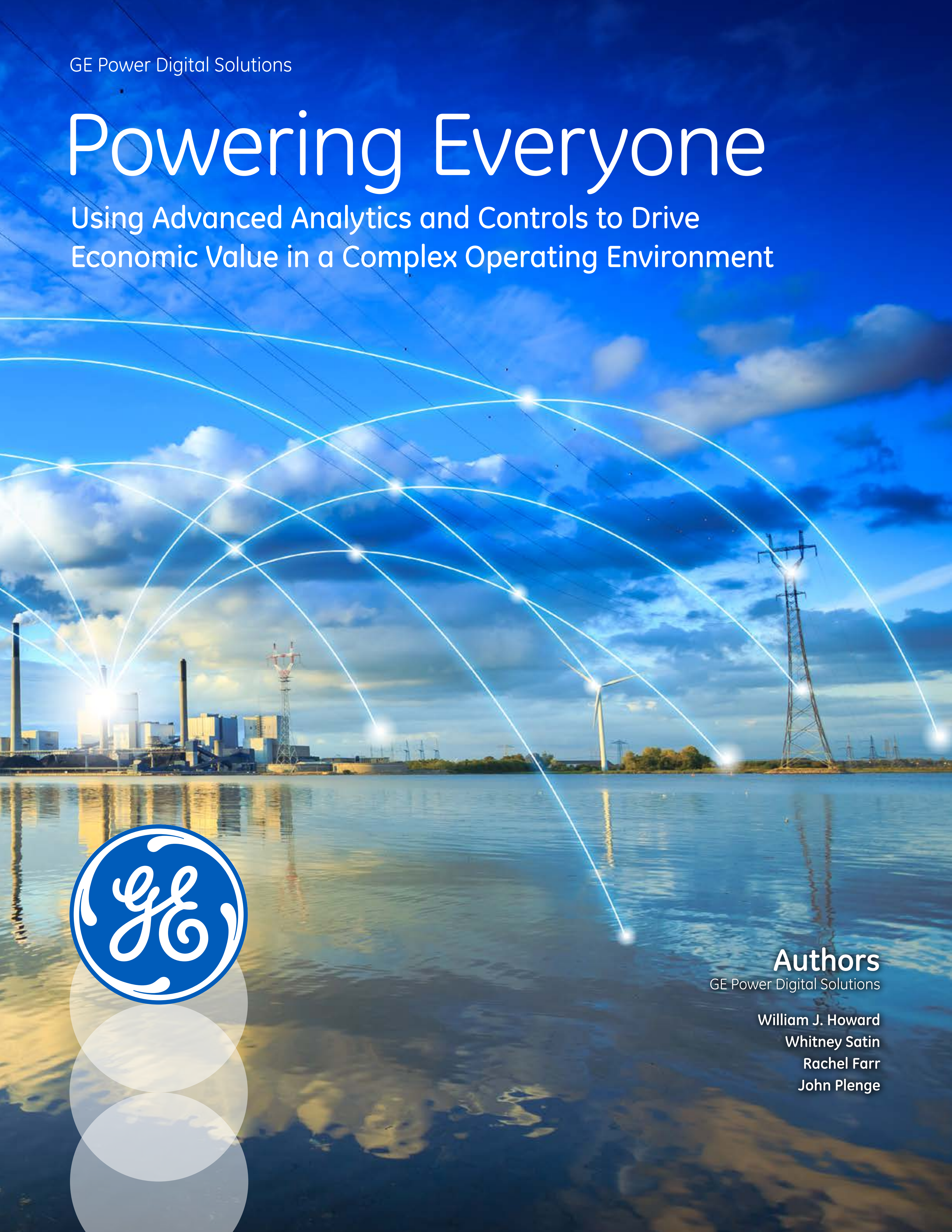

GE Power Digital Solutions

Powering Everyone

Using Advanced Analytics and Controls to Drive Economic Value in a Complex Operating Environment

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Executive Summary

A number of industries have been transformed by the wave of digital innovations, big data, analytics and computing; more recently, the power industry has begun to selectively apply these digital technologies to drive better economic outcomes for existing and greenfield power plants. These disruptive technologies are arriving at a time when the power industry is encountering dramatic market dynamics resulting from changes in fuel prices, increases in renewables coming on line, and changes in the regulatory environment. The challenges of managing power generation plants have become more complex—complicated system interactions, more co-optimization demands, and more operating profile flexibility. This convergence offers power producers an opportunity to embrace technology to re-position the competitiveness of their plant operations.

This paper demonstrates how today's power operators can use a modern ecosystem to provide on-going operational productivity—protecting against downside risk while constantly pursuing upside opportunities and increasing economic value while reducing total cost. The paper will cover a brief history of big data and applied analytics usage in power plants today, as well as the dynamics in the industry that have created new operational complexities. We present a maturity model that provides a roadmap for end users to advance through different stages of applied analytics to drive incremental and sustained productivity. We then discuss the obstacles to implementing this maturity model while specifically recommending how to progress to prescriptive analytics within the Industrial Internet architecture, moving from business applications in the cloud down to the controls layer.

Industry dynamics

In recent years, a variety of external forces have significantly impacted the way power generation companies run their assets and meet business objectives. An increase in the supply of renewables, combined with varying gas prices and a constantly changing regulatory environment, has increased the need for reliable, flexible power across generation assets. Notably, as the appetite for renewable energies increases, traditional baseload units must shift to a more cyclic operating profile. This, in turn, introduces new patterns of wear and tear that ultimately drives new maintenance needs and behaviors and impacts reliability. The complexity of this dynamic is compounded by the fact that operators must balance pressures to reduce maintenance budgets, as shorter run times have resulted in substantially lower profits overall.

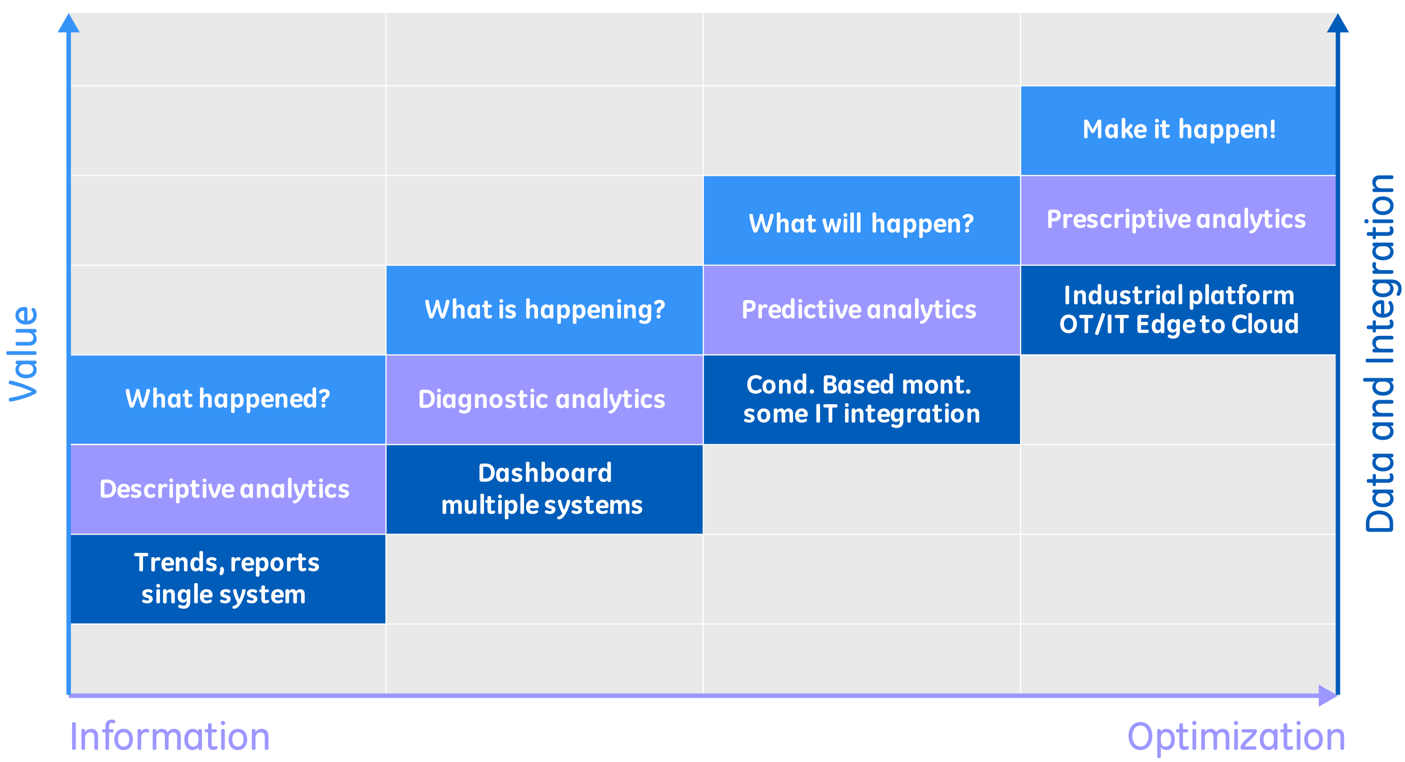
Additionally, the workforce managing today's power plants is changing, as nearly 30% of today's utility workforce is expected to retire in the next 5 years. The Bureau of Labor Statistics projects that the employment of power plant operators in nonnuclear power plants will decline by 11% from 2012 to 2022, a dynamic similar globally, which creates an environment where a smaller number of less experienced operators are tasked with operating power plants reliably. In general, the workforce is being replaced by a younger, more technologically-savvy employee who expects cutting-edge technologies similar to those found in the consumer space, which can make it hard for power companies with traditional legacy systems to attract good talent.

Industry Response

Power producers have turned to data and analytics as a way to manage these dynamics. The use of data is not new to the industry, as operators have collected and stored machine sensor data in historians for years now. Many countries face regulations that require customers to keep a minimum amount of data for a set period of time. In fact, across the power generation space, data storage is expected to have a 30% compound annual growth rate from 2014 to 2020[1]. Typically this data serves as the basis for post-issue resolution—when a machine breaks, a technician will leverage the data in determining a root cause and associated corrective action. A subset of customers have gone a step further, moving beyond basic data collection to creating simple dashboards that can highlight trends and deviations from the norm. In addition, some operators use condition-based monitoring (CBM) systems—i.e., vibration detection systems—as a means of detecting equipment issues before catastrophic failures occur.

More and more operators are considering ways to leverage data and analytics at greater scale; this includes collecting a larger number of data points, centralizing the data repository, purchasing analytic packages or additional CBM systems. More advanced operators are going a step further, looking to transform their organizations by building out centralized monitoring and diagnostic centers and the associated engineering teams. Ultimately, use cases around data and analytics can be described by a simple maturity model (Figure 1):

Figure 1: Maturity model
Move from protecting downside to enabling upside



Adapted from Gartner, 2013.

1 Based on Harbor Research and GE estimates, 2015.

As the application of analytics moves from descriptive to prescriptive, the nature of how to apply data and analytics changes from merely collecting information and doing basic trending to instead focusing on how to leverage data and analytics for true optimization. We see a shift in leveraging data to protect plants from financial downside (equipment failure leading to unavailability and expensive repairs) to enabling an upside (purposefully timed maintenance that balances operational risk and reward). As the analytics provide more valuable insights on the operational risks and opportunities, they need to be connected to both the people who make operational decisions and to the advanced controls that can adapt and maneuver the machines towards the desired outcomes.

Limitations Across Early Stages of the Maturity Model

Though early stage data collection methodologies offer some benefits to plant operators, they still have significant process inefficiencies with little impact on key performance indicators (KPIs). For example, using trend charts for root cause analysis after the fact may reduce resolution time, but it does not contribute to improved reliability of the plant—a metric valued nearly universally. It also results in a reactive approach to maintenance, meaning operators engage in significant “firefighting” as issues emerge, which often incurs high maintenance costs and reduces availability. Periodic review of dashboards can help identify issues early but introduces its own set of complications, as interpretation is often subjective and time-consuming, particularly when coupled with a field workforce that is increasingly inexperienced. Potentially severe issues may go undetected, or alternatively operators can waste time chasing noncritical issues.

Over time operators have increasingly relied on CBM systems, and while these are effective ways to detect failures, they often do so within equipment siloes and lack capabilities to enable cross-business collaboration for speedier and more accurate issue resolution. This approach also tends to reinforce a need for system specialization and extensive training at a time when workforces are getting leaner.

Challenges Moving Up the Maturity Model

More advanced operators will engage their IT departments as a way to help synthesize data across different point solutions. This enables them to start moving away from merely protecting the downside to thinking through ways to optimize the upside. By engaging with IT, these operators hope to create an ecosystem—a connection of data, networks, computers, CBM systems, and the people who use them.

Despite the best of intentions, most of these efforts fall short. Usually the connections built are simple in nature—data going one direction and aggregated in a way that makes it difficult to ultimately view the underlying parameters. For example, most data integration software can highlight the total number of events, but an operator will be unable to drill into the details that triggered the alarm in the first place, requiring a manual piecing together of the data from disparate systems to see the full picture. This adds significant time to the resolution process, complicated by the fact that most people in the organization do not have access to all the systems, which makes it difficult or impossible to connect the dots. In addition, the effort to connect systems together introduces a significant cost and level of complication related to both systems integration and data storage.

Where analytical insights point to an opportunity to adapt a machine’s operating profile, significant delays to implement these improvements can occur unless the systems are connected through compatible software models. This inability to take analytical insights and make control changes that take full advantage of the machine’s operating envelope presents yet another obstacle to achieving operational excellence.

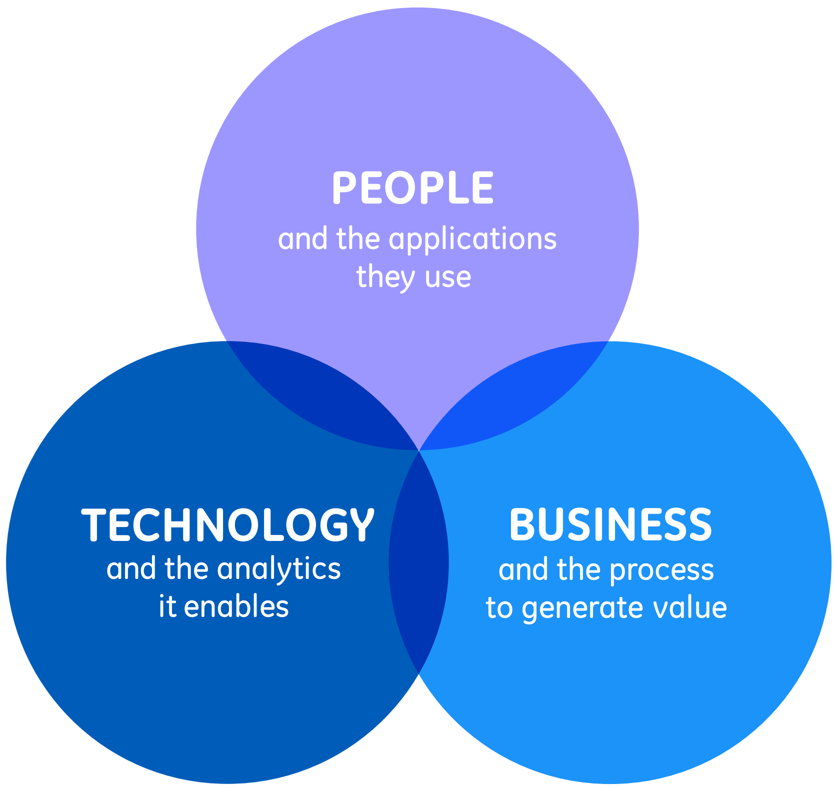
A New Paradigm: The Digital Ecosystem

To continue to create new levels of business value in today's environment, operators and critical power equipment suppliers must together think and perform in a new way—incorporating people and technology seamlessly into their business processes. Doing this requires a new infrastructure, one that is purposefully designed to enable continuous improvement while leveraging data from multiple sources, enabling more effective decision-making throughout the organization. The new digital ecosystem is designed to enable faster iterative learnings and optimization actions, an enhanced user experience across the operational team, and a new class of applications focused on targeted outcomes to create new business value.

At GE, we've built Predix™, a new industrial-grade ecosystem to accomplish the above directives, leveraging the best-in-breed of cloud technology from the consumer space and contextualizing it for the realities of an industrial setting. This helps equip plants with the digital infrastructure needed to more fully realize the benefits of advanced software models and analytics.

Figure 2: A new paradigm

Digital business enabled by Predix*



*Trademark of General Electric Company.

Cloud Technology. Industrial systems are typically built with a rigid structure, becoming obsolete as advances in technologies and needs change. Building a modern ecosystem should take this into account, allowing the system to adapt and evolve over time. We see this in the consumer space, where updates are constantly pushed to different platforms and devices and there is a general race to adopt the newest technologies quickly. This is possible because most consumer applications leverage cloud technology. From an infrastructure standpoint, cloud provides a lower total cost of ownership, elastic storage, and greater compute power. It also enables continuous seamless updates and the ability to access applications from multiple devices regardless of location. "Platform-as-a-Service" (PaaS), or a platform built on the cloud that leverages a common services architecture, is an increasingly popular concept. It provides the ability to leverage common services (i.e., visualization, authentication, etc.) to create new applications and allows for faster development, enabling developers to focus on unique value-added capabilities rather than reinventing basic functionalities.

Industrial-Specific Components. While several cloud platforms exist today, none has successfully combined key elements needed for developers to build applications geared towards the industrial space. The industrial environment introduces different-in-kind infrastructure needs: data services, asset models, and analytic services.

In most industrial settings, the thousands of sensors on hundreds of components and pieces of equipment generate data at sub-second rates, meaning that any infrastructure must have the ability to handle massive amounts of time series data. Beyond time series data, the infrastructure should enable the collection of and quick access to a variety of data sources and data types, including work order history, weather data, drawings, etc.

Second, an industrial setting needs an asset model that can integrate this data. A typical relational database model cannot efficiently handle the complexity of relationships between the different data sources, requiring a graph database model instead. A graph database allows for greater flexibility as far as analyzing the interconnections between various data points, a typical feature of today's complex business models.

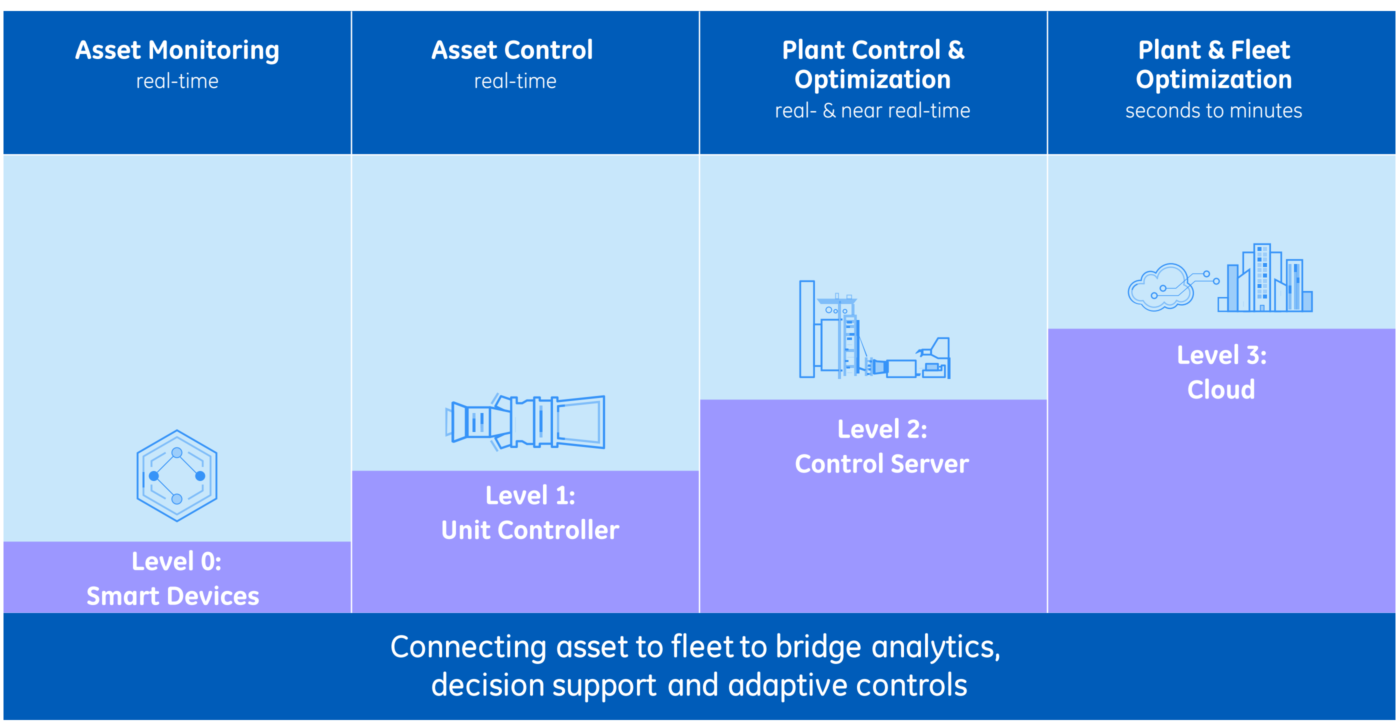
Finally, the industrial setting requires a system that can take advantage of the new asset models and data services, allowing for a new set of advanced analytics. Analytic services provide operators with the ability to test and deploy analytics rapidly across a fleet of assets, and then monitor, improve and update the analytics as needed. This iterative dynamic is a key component that enables the development and implementation of prescriptive analytics.

Plant-Level Digital Infrastructure. At an individual plant level, the local controls architecture can dramatically increase the value of advanced software models and analytics. By connecting the insights of advanced analytics to the ways in which a machine can be optimally adapted to meet a new mission objective, the controls architecture creates flexibility in the operating envelope of power plants while configuring the system throughout the lifecycle so that plants remain relevant given changing industry dynamics. This relies on both physics-based domain knowledge as well as terabytes of operational and test data, enabling plants to migrate from traditional schedule-based control schemes to system integrated model-based controls.

This advanced software modeling gives assets the flexibility to operate in a broader space, bounded by critical KPIs (e.g., output, emissions, life, ramp rate) as defined by the specific power producer at a specific point in time. In the case of complex co-optimization problems, dynamics such as trading life, heat rate and emissions can be studied through predictive simulations and then be directly implemented in the adaptive control software structure. Bridging cloud analytics, decision support, and adaptive controls gives operators the ability to consume big data from the plant and fleet to drive iterative improvements that can be quickly applied to provide better outcomes for both plant systems and individual machines. Ultimately, the greatest benefit stems from controls and data analytics maturity increasing in tandem—specifically, to the point at which prescriptive analytics enable an asset to respond dynamically to allow power producers to reach critical KPIs on a given day, week, month or year.

Figure 3: Plant-Level Digital Infrastructure

Secure, scalable, open and distributed



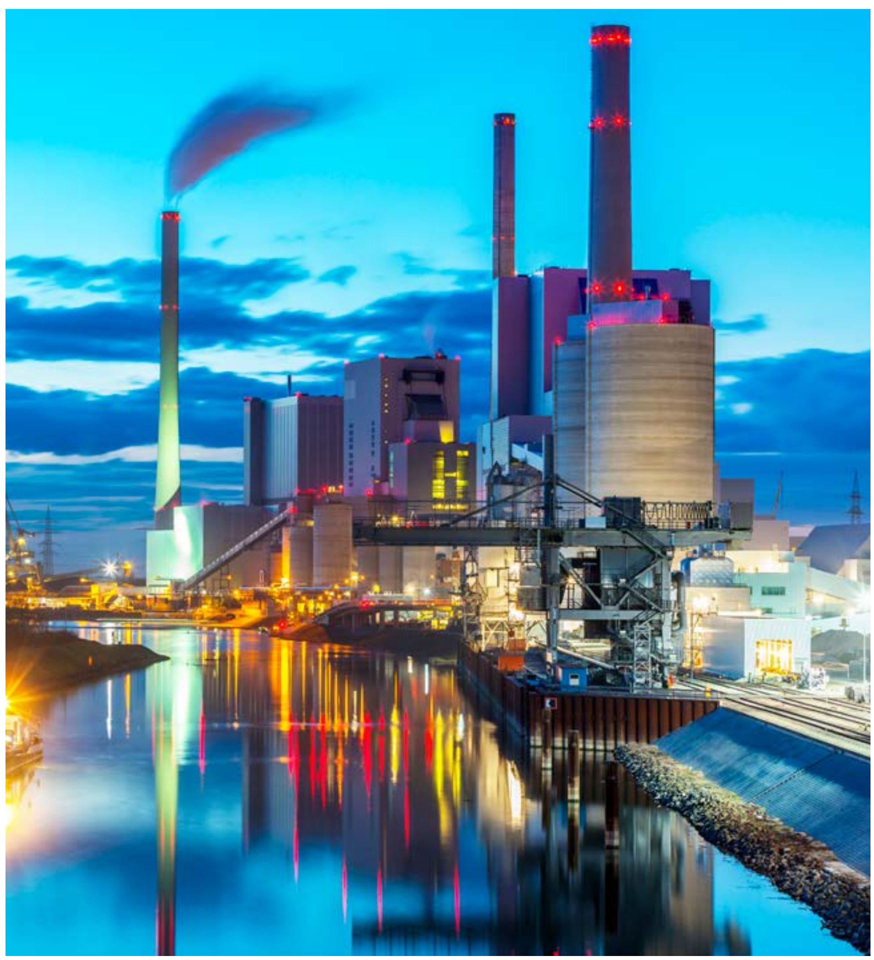
Putting the Ecosystem into Action

With the industrial infrastructure in place, operators now have the capabilities to move up the data analytic and control maturity curve to execute on the above outlined benefits of the new ecosystem: 1) iterate quickly on advanced analytics; 2) utilize an expanded operational envelope; 3) develop and make use of intuitive applications; and 4) incorporate (1), (2) and (3) into business processes and operational decisions to create additive sources of value.

Advanced Analytics. Analytics have a natural lifecycle and require multiple iterations to perfect. For example, the quality of the analytic improves by increasing the probability of detection while decreasing the number of false positives. This is made exponentially easier when analytics are written by engineers with deep domain knowledge. Analytic maturity is also a factor. As analytics move up the maturity curve (Figure 1), they transition from descriptive to prescriptive—no longer detecting issues but predicting them and automatically giving recommended action on how to proceed. All told, the faster operators can iterate, the faster they can create a high quality, prescriptive analytic—which ultimately delivers greater business value. This also highlights the importance of having an infrastructure that supports analytic services, giving operators functionalities like a sandbox to create and test analytics, as well as the mechanism to rapidly deploy and monitor their quality metrics.

Even the more advanced analytics require that operators further investigate the alert after an initial trigger. Having an application that captures that initial diagnosis, collaboration, and issue resolution and can feed these inputs back into the analytic development process is an important means of moving analytics to the prescriptive phase. When coupled with an on-premise digital infrastructure that runs advanced software modeling, high quality prescriptive analytics will eventually lead to machine learning and full process automation as exposure to data increases—this ultimately will create the fastest time to economic value.

Advanced Software Modeling. Incorporating high fidelity physics-based models, or "digital twins," of plant components into controls and connecting them at a system level opens up an operational envelope not otherwise available. These models are the backbone of adaptive control strategies that protect assets and enhance operation. Various performance models can be integrated and tuned to meet a specific desired outcome in terms of efficiency or output with greater reliability real time. These advanced software models can be applied at different levels of the architecture, depending on the functional objective: fleet analytics, process optimization or real time machine control. When models are linked across the assets at the plant level, they can be used to reach an optimal integrated performance, such as the fastest or most efficient start for a combined cycle plant.



Intuitive Applications. Applications are a way to connect people and technology to achieve business outcomes. As discussed, they provide a way to take the domain knowledge from operators and feed it into the analytic development process. Additionally, applications enable the visualization of a wide variety and quantity of data across multiple assets, enabling operators to work with the data through an intuitive interface and potentially uncover new insights. Because these applications leverage cloud technology, they enable operators to seamlessly collaborate from anywhere. Finally, when advanced software models and controls are coupled with prescriptive analytics and an intuitive application interface, operators are armed to drive better outcomes than ever before. These factors ultimately enable more effective decision making across a wide variety of daily business processes.

Business Value. Equipped with analytics and applications, power generators now have opportunity to derive additional business value across their operations. Several GE customers have helped pioneer a variety of both cloud-based and on-premise applications, improving the reliability and operability of assets in today's complex operating environments.

Bord Gáis Energy

The 445-megawatt Whitegate gas combined-cycle power plant, owned by Bord Gáis Energy, is located 25 miles east of the city of Cork, and provides power to 10% of Ireland. With European government regulations demanding more renewable energy production, in turn creating a greater need for reliable, on-demand generation capacity, Bord Gáis Energy understood it needed to prepare the Whitegate station for future grid challenges.

Bord Gáis Energy required a solution for condition-based monitoring at the Whitegate plant to ensure continuous operation toward no unplanned downtime. They chose GE's Asset Performance Management (APM) solution providing a single, consolidated view of plant performance. The solution is powered by GE's enterprise platform Predix.

The Whitegate implementation of APM on GE's Predix platform reduced plant downtime and plant operating costs. With APM, early warnings of failure mechanisms using 300 algorithms detect when plant components are about to fail, allowing for more efficient outage management. The integrated solution has created a €2,28M positive financial impact from cost savings and cost avoidance without any plant unavailability due to covered equipment and 21 additional "catches" by the system.

RasGas

RasGas is one of the worlds' premier integrated liquefied natural gas (LNG) enterprises that transformed a regional resource into a key component of the global energy mix. RasGas is a Qatari joint stock company with more than 3,000 employees, owned by Qatar Petroleum (70%) and ExxonMobil (30%). Qatar remains the largest LNG exporter, providing 77 MTA to the market, which is roughly one-third of global supply. The LNG production at RasGas in Ras Laffan, Qatar, consists of seven LNG production trains with an approximate capacity of 37MM Tons a year. RasGas is focused on cost and value optimization to reduce overall expenditures and enhance efficiency by improving plant reliability and availability without compromising safety, health and the environment.

The initiative at RasGas began in late 2014 with a pilot for early detection of equipment or system failures and production optimization for selected units of three (3) LNG trains. This covered GE & non-GE equipment with GE's Asset Performance Management (APM) solution, built on the Predix cloud platform, using machine data sensors, predictive analytics and process optimization. GE's APM solution empowers RasGas with asset anomaly detection through a unified user experience covering both GE and non-GE assets, providing alerts, alarms, historical analysis with the visibility into asset performance and health. The intention of RasGas's APM analytic solution was to reduce unplanned downtime, improve productivity and reliability, and to move from reactive to predictive maintenance for rapid recovery.

The GE team worked closely with the RasGas team to develop and identify opportunities for a pilot project to detect early failures and production optimization initiatives by leveraging a consolidated store of collected machine sensor data, analytic software and a platform that provides a plant-wide view. By mid-2015, the pilot project had demonstrated initially that early failures and process optimization opportunities can be detected with the use of analytics with the ability to identify areas to optimize and reduce waste.

In the summer of 2016, GE inaugurated the world's most efficient gas turbine combined-cycle power plant (62.2%) in Bouchain, France in association with Électricité de France (EDF)—a 609MW 1x1 9HA.01 plant. This milestone demonstrates a new era of power generation technology and digital integration possible for power plant projects. The project began by harnessing the more than five terabytes of data collected from the HA test facility in Greenville, South Carolina, where the 9HA was tested in a full scale, full load test cell. Learnings from the GE fleet were then used to develop extreme test scenarios to exercise the machine's design boundaries. The findings resulted in refinements to the advanced software models used for controlling the 9HA gas turbine, effectively expanding the operating envelope and enabling the industry leading performance demonstrated.

GE pioneered the use of model-based control software that precisely models the machine's physics, a technique instrumental in the performance and operability growth of the industry leading F-Class gas turbine and one implemented at the onset with the HA platform. The Bouchain plant specifically demonstrates the benefits a digitally-integrated plant can provide. For example, to provide a combined cycle plant capable of reaching full power in less than 30 minutes, this advanced control technique must manage in a coordinated fashion the turbine thermal stresses, steam process stability, emissions and output during the start sequence.

The full automation of the power island not only enables fast plant start maneuvers but also helps reduce process variances and improves start reliability. To achieve these outcomes, Bouchain utilizes a state-of-the-art user interface that brings into focus the critical components of an operator's task while filtering out distracting information. For example, the HMI organizes and presents the supporting information for the disposition workflow as important alerts emerge; this newly designed user interface can reduce nuisance alarms by as much as 80%. Furthermore, this automation framework helps operators establish a stable process, one that is predictable so that improvement opportunities can be quickly identified and implemented.

Summary

Today's environment requires that operators rethink the basic definition of how technology adds value to the business. Equipped with an increasingly dynamic set of prescriptive analytics and a larger operating envelope, accessed through the right application and supported by an industrial-grade platform, businesses now have the ability to move from using data for information to instead using it to drive towards optimization. This is a continuously evolving process, not only because it takes time to infuse the analytics and applications with the domain knowledge and expertise, but also because business objectives and operating environments are rarely stagnant. An ecosystem that allows for rapid iteration of analytics provides the flexibility and resources needed for organizations to continuously adapt to all the complexities—both today and in the future.

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